

Physical Performance Decrements in Military Personnel Wearing Personal Protective Equipment (PPE)

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ABSTRACT

Introduction

The load of personal protective equipment (PPE) body armor affects physical performance of trained military personnel. A balanced effect of injury prevention and performance optimization is desired.

Rationale

To assess PPE on physical performance by cardiovascular, balance, strength, and functional field tests.

Methodology

Twenty-one physically active U.S. military volunteers on active duty (19 males, 24.2±3.7yr, 180.1±5.4 cm, 82.9±11.0 kg; 2 females 23.0±0 yr, 161.3±14.4 cm, 56.1±6.7 kg) participated in an experimental repeated measures counter-balanced design study. All subjects completed a battery of physical performance tests with

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and without a PPE system of Kevlar® front and back plates and an unlined combat helmet. The average mass of the PPE system was 9.8 ± 0.9 kg. Aerobic capacity ($\text{VO}_{2\text{max}}$) was measured using a metabolic cart (SensorMedics Vmax 29c, Yorba Linda, CA) while subjects performed a specific treadmill test of fast walking up steep grades. Upper extremity climbing strength was evaluated using a BTE Primus RS dynamometer (BTE Technologies Inc, Hanover, MD) measuring work output over a 30 second maximal effort with analysis of joules and repetitions. Balance was assessed in four different postural conditions immediately before and after the treadmill (exercise) test. All participants stood on a Bertec force platform (Model BP5050) with their arms on their hips. Each subject's motion was determined by examining changes in the anterior-posterior and medial-lateral center of pressure (COP). Functional field tests assessed anaerobic running (300 yard shuttle run), agility (box agility), and upper extremity power (rope pull and dummy drag) on a separate testing session. Separate repeated measures analysis of variance tests were conducted for each dependent measure (alpha level .05 set a priori).

Results

Treadmill time was significantly reduced by PPE from 16.4 ± 1.6 min to 14.4 ± 1.5 min; $p < 0.001$. PPE also resulted in a significant decrease in aerobic capacity from $48.3 \pm 5.7 \text{ ml} \cdot \text{min}^{-1} \cdot \text{kg}^{-1}$ to $42.9 \pm 4.9 \text{ ml} \cdot \text{min}^{-1} \cdot \text{kg}^{-1}$; $p < 0.001$. Analysis of upper extremity climb data showed a significant effect of PPE on the number of repetitions ($p=.001$), but no significant differences in work (joules) as a function of PPE ($p=.18$). Individuals completed five more climbing repetitions while not wearing the PPE (Control = $51.3 \text{ reps} \pm 11.2$ vs. PPE = $46.38 \text{ reps} \pm 11.1$). Analysis of COP data demonstrated significant changes in mean COP motion in both the anterior-posterior (AP) and medio-lateral (ML) directions as a function of fatigue and PPE (all p 's < 0.05). Postural sway in both the AP and ML directions increased after fatigue and when the subject was wearing PPE. Analysis of field tests revealed significant differences between PPE and control conditions for the shuttle run ($p<.001$), but no significant differences for the box agility test ($p=.28$) or upper extremity power rope pull and dummy drag test ($p=.42$).

Conclusions

PPE was associated with decrements in cardiovascular, balance, strength, and functional field test performance. Future research is required to evaluate the effects of PPE specific training programs to reduce performance decrements and to determine PPE optimal weight and configuration.

INTRODUCTION

Soldiers are faced with a great number of hazards during combat, training, and completing other tasks in the workplace. Musculoskeletal injuries are the most common type of injuries in military personnel during training [1]. Noncombat musculoskeletal injuries are not as well documented in theater but account for a significant operational burden. Body armor and other personal protective equipment (PPE) provides a level of protection from penetrating trauma [2]. The deleterious effects on the musculoskeletal system have been documented [2]. PPE adds additional weight, creating a load carriage system that as such can inhibit the soldiers' mobility and have a physiological effect on the body. PPE is associated with increased heart and respiratory rates and cause muscle fatigue and injuries [2]. The amount of energy used for walking increases as the amount of load carriage increases, speed increases, or terrain changes [3]. The biomechanical effects of load carriage systems, including but not limited to personal protective equipment, have been investigated. Load carriage systems have been found to increase knee range of motion, forward lean of the body and increased moments at the head and trunk to counterbalance the weight of the load [4]. During 6 km/hour

marches for 40 minutes on a treadmill at 0, 15 and 30% body weight, physiological responses (i.e., oxygen consumption, carbon dioxide production, expired ventilation, respiratory exchange ration and heart rate) increased proportionally as the load increased as well as of peak stance knee flexion [5].

While several studies have been completed on the effects of load carriage on physiological, kinematics and kinetics [4, 6, 7], there have been no comprehensive studies examining the effects of personal protective equipment (i.e., body armor and a helmet) on cardiovascular, postural control, reaction time and functional field tests on physical performance in a military population (REFS). Therefore, the purpose of this study was to investigate the effects of PPE on physical performance based on a physical performance assessment developed for a military population at Old Dominion University.

METHODS

Twenty-one physically active volunteers from various U.S. military commands [(19 males, 24.2±3.7yr, 180.1±5.4 cm, 82.9±11.0 kg, 2 females 23.0±0 yr, 161.3±14.4 cm, 56.1±6.7 kg)], who had experience wearing PPE participated in this study. Volunteers were tested with and without a PPE system, which consisted of a helmet and a vest with chest and back ceramic plates. The vest came in different sizes (small and large) to provide an appropriate fit so the PPE mass varied slightly among subjects. The average weight of the PPE system was 9.8kg ± 0.9kg. The volunteers wore their military issued battle dress uniforms, including military boots and socks which were also worn during postural control testing. The subjects were tested on two different days (with and without PPE) with a minimum of three days in between testing sessions. Cardiopulmonary, postural control, and functionally relevant tests were administered. All subjects were in good physical health and had no current history of injury or illness that would preclude participation in performing physical performance tests in the study. Prior to participation, all subjects were required to sign an informed consent form that was approved by two different institutional review boards (Old Dominion University and Naval Medical Center Portsmouth).

Cardiopulmonary Testing

Cardiopulmonary testing included a maximal incremental treadmill test. The treadmill test was specifically designed to present a functional challenge of practical warfighting significance, carrying a load up a steep hill as opposed to unloaded running. Stages were three min each in duration, beginning at 3 mph (4.8 kph) and 0% grade, then 4 mph (6.4 kph) and 0% grade, followed by 5% increases in grade each three min until reaching 20% grade. A planned increase to 4.5 mph (7.2 kph) and 20% grade was not attained by any subject in this study. For the treadmill test, subjects were fitted with a mouthpiece for collection of expired gases and a chest strap heart rate monitor (Polar, Kempele, Finland). Gases were analyzed by the Vmax metabolic cart, which was calibrated with known concentrations of O₂ and CO₂ prior to each test. Maximum oxygen consumption (VO₂max) was determined as the highest VO₂ over three consecutive 20-sec periods. Subjects were verbally encouraged to exercise as long as possible.

Balance Testing

Static forceplate tests, Star Excursion Balance Test (SEBT), Balance Error Scoring System (BESS), NeuroCom Smart Balance Master Sensory Organization Test (SOT) were administered with and without PPE gear. Static forceplate balance was assessed in four different postural conditions immediately before and after the treadmill (exercise) test. All participants stood on a Bertec force platform (Model BP5050) with their arms on their hips. Each subject's motion was determined by examining changes in the anterior-posterior and

medial-lateral center of pressure (COP). During the SEBT, the volunteers were asked to stand in the middle of the testing grid while keeping their hands on hips and their stance heel on the floor throughout testing. While maintaining this position, the subjects were asked to reach with their reach leg along the tape and tap their toe lightly on the furthest point that they could before returning to the starting position. Subjects had 4 to 6 practice trials until comfortable performing the task appropriately in each direction before 3 trials for each were recorded for analyses. Both dominant and non-dominant legs were tested. The Balance Error Scoring System (BESS) required the volunteers to perform three positions (double leg, single leg, and tandem) both on the floor and on a foam surface. Subjects were instructed to stand quietly with their hands on their hips and their eyes closed. Each trial lasted 20 seconds, and during that time, the number of errors was counted. Errors included lifting hands off the hips, stepping, stumbling, or falling, lifting the forefoot or heel, opening eyes, moving hips into more than 30 degrees of flexion or abduction, and remaining out of the testing position for more than 5 seconds. For the NeuroCom SOT, subjects were asked to stand on the force plate with the lateral aspects of their feet lined up according to the manufacturer's standardized height scale. Subjects were asked to stand quietly with their arms by their sides and head facing forward, while performing three trials of each of the six testing conditions; each trial lasted 20 seconds. The 6 testing conditions were: 1) normal vision, fixed surface; 2) eyes closed, fixed surface; 3) sway referenced vision, fixed surface; 4) normal vision, sway referenced surface; 5) eyes closed, sway referenced surface; and 6) sway referenced vision, sway referenced support. Prior to each testing condition, the subject will be instructed that his/her surroundings and/or support may or may not move.

Functional Testing

Strength, power, agility and speed assessments included an upper extremity climbing assessment and field-based testing tasks. Upper extremity climbing strength was evaluated using a BTE Primus RS dynamometer (BTE Technologies Inc, Hanover, MD) measuring work output over a 30 second maximal effort with analysis of joules and repetitions. Field-testing included a 300-yd (274-m) shuttle run using 25-yd (23-m) repeats, and a 4 by 10-yd (9.1-m) box drill (sprint forward, side shuffle, run backwards, carioca), and upper extremity power (rope pull and dummy drag).

Statistical Analysis

Separate repeated measures analysis of variance tests were conducted for each dependent measure. The alpha level was set at 0.05.

RESULTS

Analysis of treadmill time was significantly reduced by PPE from 16.4 ± 1.6 min to 14.4 ± 1.5 min; $p < 0.001$. PPE also resulted in a significant decrease in aerobic capacity from 48.3 ± 5.7 ml·min⁻¹·kg⁻¹ to 42.9 ± 4.9 ml·min⁻¹·kg⁻¹; $p < 0.001$. Analysis of upper extremity climb data showed a significant effect of PPE on the number of repetitions ($p=.001$), but no significant differences in work (joules) as a function of PPE ($p=.18$). Individuals completed five more climbing repetitions while not wearing the PPE (Control = 51.3 reps ± 11.2 vs. PPE = 46.38 reps ± 11.1).

Balance testing showed mixed results. Analysis of COP data demonstrated significant changes in mean COP motion in both the anterior-posterior (AP) and medio-lateral (ML) directions as a function of fatigue and PPE (all p 's<0.05). Postural sway in both the AP and ML directions increased after fatigue and when the subject was wearing the PPE. Analysis of field tests revealed significant differences between PPE and control

conditions for shuttle run ($p < .001$), but no significant differences for box agility test ($p = .28$) or rope pull and dummy drag test ($p = .42$).

DISCUSSION

The most important finding of this study was that PPE resulted in changes of cardiovascular, postural control, upper extremity functional strength and functional field test performance. Surprisingly, PPE was associated with a significant decrease in aerobic capacity. In this cohort of healthy and fit subjects, the expected result would be an increase in heart and respiratory rates with maintenance or increase in the aerobic capacity. The decrements in the upper extremity function and the possible restriction by the PPE vest of chest wall motion may be the cause or have contributed to this result. Future studies should be conducted on the stationary effects of the PPE vest on aerobic capabilities.

PPE also has an effect on the COP measurement during postural sway, but no statistically significant effect on the BESS, SOT or SEBT. This suggests that the BESS, SOT and SEBT, typical clinical measures used in a sport and rehabilitation environment, were not sensitive enough to detect the effects of PPE. Balance tests on subjects wearing weighted vests in studies specifically designed to evaluate the effect of added weight on balance demonstrate a decrease in clinical balance (altered jump landing or abnormal compensation to perturbed gait) related to the amount of weight (REFS). That our study did not reflect such differences is most likely a function of the test sensitivity. The amount of gross body movement required in the BESS and SEBT is relatively minimal compared to normal military function. Additionally, the Neurocom SOT only stresses the anterior-posterior direction of postural control during a stationary stance on a double-limb support that may not be sensitive enough to detect changes relative to PPE gear. Future studies should evaluate more dynamic postural control tasks (e.g., jump-landing stability) to assess the effects of PPE gear relative to dynamic tasks.

Wearing body armor has been shown to increase the amount of energy the body requires⁹ and physiological responses (including O_2 consumption, CO_2 production, and heart rate) increased proportionally as the weight of the load increased [5]. These findings are supported by the decrement in cardiovascular performance measured in this study. Additionally, load carriage has been shown to reduce work performance and increase fatigue [3], which is also supported by the decrement in the upper extremity work test and the functional field tests.

CONCLUSIONS

The use of body armor was associated with decrements in cardiovascular, balance, strength, and functional field test performance. The decrease in aerobic capacity was not expected. Future research is required to evaluate the effects of PPE specific training programs to reduce the performance decrements armor and to determine the optimal weight and configuration of PPE. We are currently investigating PPE with respect to aerobic capacity, balance, combat related tasks (including sprinting and a fatigue march), and cognition as a function of fatigue.

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